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Thesis

~~A REVIEW OF~~ THE ATOMIC ENTITIES

by

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~~A REVIEW OF~~ THE ATOMIC ENTITIES

INTRODUCTION

This paper comprises an attempt to outline briefly those most noteworthy developments in the field of the structure of matter. We have simply selected those experiments for review which established definite electronic entities and their corresponding constants. Somewhat further, we have sketched briefly an account of those properties, especially of the fundamental electron and proton, which have contributed materially to the discovery and development of those comparatively new particles, viz., the neutron and the positron. It would be quite impossible, within our limited scope, to review all the main electronic characteristics or to outline the various theories with all their ramifications. Rather, in this respect, do we merely employ accepted values and procedures from them as the case may require. General atomic theories we present in barest outline, since they have served as stimulus for further research and development leading to the new electronics. The order is purely chronological.

I

EARLY CONCEPTIONS OF MATTER

From the time of the first recorded philosophers and undoubtedly before, man, prompted by his insatiable curiosity, has been prying into the ultimate constituents of matter. It is a strange coincidence to note that the first general conceptions are basically the same as those which, fortified experimentally, are held today. That the world consists of minute particles, incessantly moving, was held by Democritus, 425 B.C., Epicurus, 275 B.C., and Lucretius, 50 B. C. This notion was merely philosophic speculation based on the expansion of the prime notion of Thales, 600 B.C., who formulated the idea of "primordial matter", which idea constituted the seed from which all developments, to this very day, have sprung. Remarkable indeed, is Thales' search for the unifying principle, in the form of some primordial element, that would link together and explain all natural phenomena. And further remarkable that his discovery of electrification, actually unintelligible to him, should eventually lead to his much sought goal.

Later Developments

Primarily because of the lack of development of quantitative experimentation, little was contributed through the centuries to atomistic advance until the advent of the

work of John Dalton (1805 A.D.). Dalton, on whose work is founded the science of chemistry, empirically discovered his Law of Multiple Proportions from which has grown our conception of the nature of molecules built up of atoms, of which there are as many as there are kinds of elements. Basing his work on the idea of Dalton's, Prout, in 1815, proposed the hypothesis which boldly stated that the atoms of all elements are built up from atoms of hydrogen, the lightest of all elements. The suggestion was offered that all atomic weights, relative to hydrogen, are whole numbers. This theory was later exploded upon detection of deviations in integral values in many atomic weights. It was, however, still later revived by modern science with the theory of nuclear charge and isotopy of the elements. The first half of the 19th century was extraordinarily fruitful in many respects. The atomistic picture took new width in the notions of Clausius and Joule developing older conceptions of the kinetic theory of gases and in further development by Clark Maxwell with researches on viscosity. The discovery of the first absolute magnitude of a particle is credited to Loschmidt when, as a result of considerations in the fields of viscosity and liquefaction of gases he was able to compute the size of the molecule,- this was in 1865.

We have neglected one important event which served to verify visually these early conceptions. Robert

Brown, a Scotch botanist, in 1827 discovered the remarkable, irregular motions of pollen, with dimensions of the order of a two-hundredth part of a millimeter, suspended in a liquid under a microscope. This phenomenon was explained later as due to the internal molecular motion of the liquid.

The Nature of Electricity

Along somewhat similar lines of individualization did the early idea of electricity grow. The first electrical theory, based on the recognition of opposite electrical charges, is due to Franklin in the eighteenth century, when he developed his electrical "fluid" conception. A later adaptation was the two-fluid theory of Symmer, who defined electrical neutrality in matter as containing as constituents equal amounts of two weightless fluids which he called positive and negative electricity. Franklin, however, conceived of his electricity as matter, and indeed, he received his first experimental support from Faraday 85 years later. Faraday discovered his simple laws of electrolysis which explain chemical decomposition in liquids by means of an electric current. It was found that the same current required to produce a gram of hydrogen at the negative terminal would always deposit from a silver solution exactly 107.8 grams of silver, thereby definitely associating the atomic weight of silver as 107.8 times that of hydrogen. It was further found that

univalent atoms combining with one atom of hydrogen carry precisely the same amount of electricity, bivalent atoms twice the amount, etc., and this has led indirectly to the search for that fundamental charge or elementary quantum of electricity.

However, the material aspects of electricity fell from view to some extent in the latter part of the 19th century with the advent of Maxwell's electromagnetic theory of light. Based on electromagnetism, it was contended that an electrical charge on a body is a "state of strain" in the surrounding medium[1] and the passage of a current in a conductor is simply the breakdown of this state of strain. Maxwell's investigations are a product of the then acquired knowledge of electrical and magnetic "fields" and the periodic variations of these field strengths to form electric and magnetic waves. In passing, he further deduced from these considerations the facts that electric and magnetic waves co-exist with equal velocity; that electromagnetic waves are pure transverse waves since the magnetic field strength is always perpendicular to the electric, and both are perpendicular to their common direction of propagation, thereby explaining the phenomenon of polarization. In attempting to determine the velocity of these electromagnetic waves, Maxwell seized upon the calculation of Wilhelm Weber who found the ratio between the electrostatic system of units and the

1. Milliken's Electron, p.18, University of Chicago Press, 1918.

electromagnetic and found it to be a constant, representing velocity. Taking this constand plus those constants of the dielectric and of the magnetic permeability, it was found the velocity of electromagnetic propagation in vacuo equals the velocity of light. Maxwell associated, then, light waves with electromagnetic waves, explaining light phenomena without artificial hypotheses and improving infinitely on Huygen's and Fresnel's theory of light as longitudinal, mechanical waves. Real confirmation was forthcoming when, in 1888, Heinrich Hertz, by purely electrical means, produced waves which conform in velocity, transmission, etc., to the corresponding properties of light.

Despite the emphasis throughout this era on the so-called "ether-strain" concept of electricity, Weber developed a theory of electromagnetism which rested on the assumption that there existed two electrical constituents of atoms, one more mobile than the other[1]. He conceived the Amperian molecular current to consist of light, positive, charges in rotation around heavy, negative ones, both particles of mass. But withal, the two contrary conceptions persisted even to some recordings of Lord Kelvin in 1897, when cathode and positive ray analyses, X-rays, and other phenomena of which we shall now treat, were under investigation.

1. Milliken's Electron, p.20, University of Chicago Press, 1918.

II

THE ELECTRON AND THE PROTON.

The Electron Theory

In 1876, Rowland, by rotating a charged plate rapidly and thus deflecting a magnetic needle, showed that a moving electrical charge has the same properties as an electric current. Following this, five years later, Sir J. J. Thomson attributed to a moving charge inertial mass since this charge, producing a magnetic field, demands energy to produce the motion with its consequent results. The charge, then, acts as though endowed with a definite mass, called electromagnetic mass. This mass, it was further found, is proportional to the square of the charge and, inversely, to the radius of the sphere. Based, then, on the concomitant ideas of electrical and mechanical laws applying to electrical charges, Lorentz, in 1895, formulated the electron theory, an extension of Maxwell's. He established the picture of electrical charges, each of one elementary quantum charge, in motion in the molecule. After Stoney, these particles were called electrons. The effect, discovered by Zeeman in 1896, of a magnetic field resolving spectral lines in the field, verified Lorentz' theory. It showed, in addition, that the charge per unit mass, "specific charge", of the particles producing the effect was 1800 times greater than for ionized

Hydrogen atoms, and if each charge is elementary, then the mass of the particle is one eighteen hundredth the atom of hydrogen.

Cathode Rays

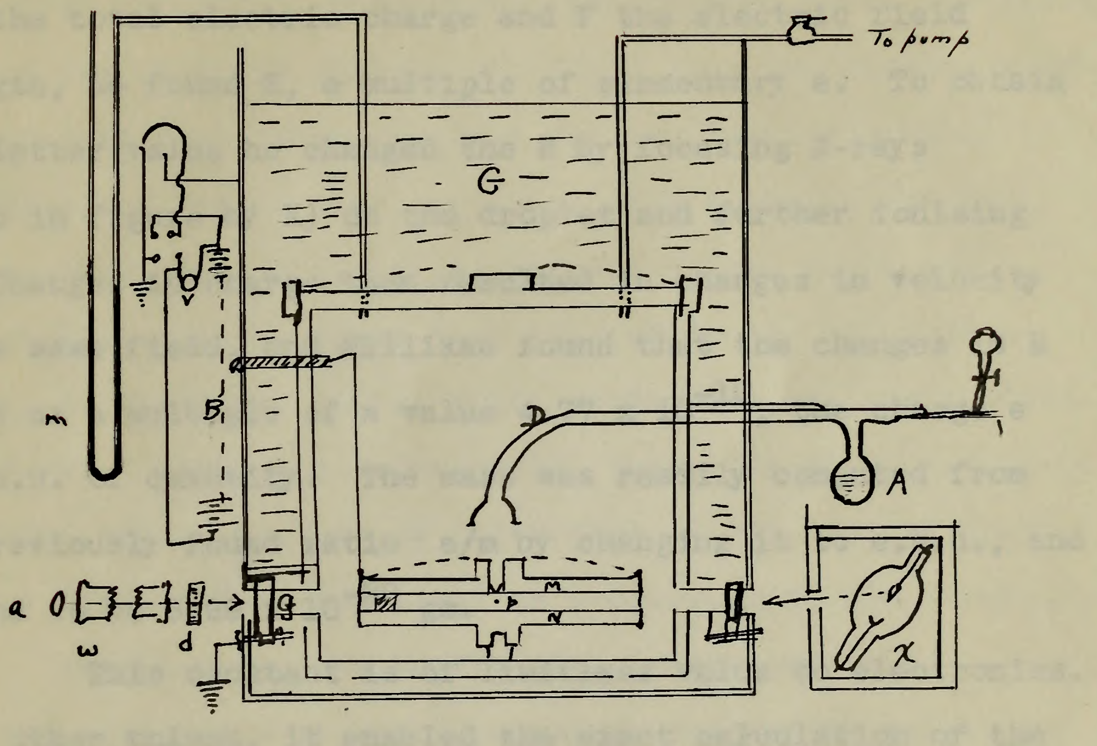
In the year 1858 Plucker discovered the existence of cathode rays emanating from the cathode of a tube containing gas at low pressure through which a current of electricity was flowing. The study of conduction through gases was continued and subsequent improvements were made, notably by Geissler and Crookes. Up to the time of J. J. Thomson in 1897, the rays were known to travel in straight lines, to be penetrating, to exert mechanical pressure, to be heating, to be deflected in a magnetic field, and to charge an electroscope negatively. It would seem that the exact nature could be proven upon determination of the rays' behaviour in an electric field. Thomson found that in a highly evacuated tube the particles were deflected as though they were negative charges, proving their nature. Further, Thomson found quantitatively, by employing both the magnetic deflection and the electric, the ratio e/m, wherein e is the charge and m the mass, and the velocity of the particle (this latter being 1/3 that of light). The ratio of e/m he found to be constant regardless of what gas was in the tube and he established the identity of this negative particle as an electron, a common constituent of all gases. The velocity varies with

the tube potential.

The discovery of X-rays by Roentgen in 1895 aided in this study since it was soon found that all substances on which these rays impinged emitted electrons. Earlier yet, in 1888, Hallwachs had found that ultra-violet light falling on certain metals caused electrons to be liberated, the "photo-electric effect". Electrons, then, seemed to be the common constituents of matter.

Determination of the Elementary Quantum of Electricity - e.

Townsend, Franck, and others attempted to compute the elementary charge, e, but reached inaccurate values. Not until 1906 did Robert Millikan succeed in definitely establishing this much sought value. Because it has given the most exact value with comparatively simple apparatus, we shall review briefly his experiment of 1910 with oil droplets in an electric field. The apparatus is shown here -



Millikan's[1] Oil-Droplet Apparatus - for determining Charge e.
A, atomizer; M and N, electrically charged plates from battery, B; a, arc magnified and cooled through w and d; G, heat insulating oil compartment; p, oil droplet in field.

Observing the fall of the atomized charged oil drops into the chamber between the plates M and N (which act as a condenser), Millikan computed the velocity due to fall, making careful correction of Stokes Law of frictional force for low velocities, and the velocity of ascent which the frictionally ionized particle acquired when the charges on the plates were reversed. He then determined the mass m of the droplet from its density and the corrected version of Stokes Law, substituting in his derived equation $E = mg/F \left(\frac{v_2 + v_1}{v_1} \right)$, wherein

1. Millikan's "The Electron", 2nd Ed., 1924, p.118, University of Chicago Press.

E is the total electric charge and F the electric field strength, he found E, a multiple of elementary e. To obtain this latter value he changed the E by focusing X-rays (shown in figure by X) on the droplet and further ionizing it. Changes in charge then resulted in changes in velocity in the same field, and Millikan found that the changes in E varied as a multiple of a value 4.77×10^{-10}, the charge e in e.s.u. of quantity. The mass was readily computed from the previously found ratio e/m by changing it to e.s.u., and m found to be 8.99×10^{-28} gm.

This constant is of limitless value to electronics. Among other things, it enabled the exact calculation of the Avogadro number, i.e., the number of molecules in 1 gram molecule, another important constant.

<u>Radioactivity - Alpha Ray Analysis - the C. T. R. Wilson Cloud Apparatus.</u>

That uranium of itself emits penetrating, ionizing, charged rays was the discovery of Becquerel in 1896. M. & Mme. Curie two years later discovered a new element which they called radium, emitting these radiations. Further investigations revealed a series of somewhat similar heavy elements endowed with these properties.

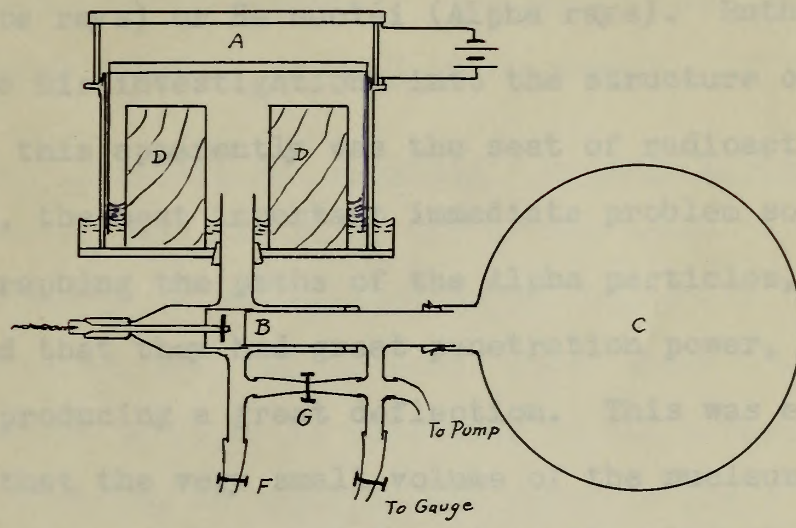
Becquerel himself promptly tested these rays and found them deflected in a magnetic field as negative particles when emitted from uranium, but as positive particles when

emitted from polonium. Rutherford investigated these particles, found the specific charges, and found that the former, which he called Beta rays, were electron streams just as cathode rays, while the latter were particles of a positive charge 2. By firing these latter particles through a thin glass tube into a neutral gas, he found that they evidently acquired a negative, neutralizing charge which produced a gas the spectroscope revealed as Helium. Obviously, then, the alpha particles are ionized Helium nuclei. A third type of ray, called gamma rays, was found almost identical in properties to the X-rays.

To determine the charge on an alpha-particle Rutherford employed a piece of apparatus devised by Geiger and called a Geiger counter. This consists essentially of a highly charged needle in a low charged metal container, insulated from it. As an alpha particle, directed at the needle, comes into the intense electrical field in the vicinity of the needle, heavy ionization naturally results, producing a current strong enough to be recorded by a galvanometer,- ionization then instantly ceasing. Each alpha-particle can then be recorded and the ionizing charge produced can be carefully noted. It was indicated, from e/m etc., that the particle indeed was doubly charged with a mass 4, the He nucleus. From this method, as well as from the scintillation method (which consists in allowing the radiations to fall on screens and the flashes counted coming from radiating sources of

known size), the number of emanating particles can be computed.

By a study of the scattering power of thin foils, an insight was gained as to the particular constitution of these particles. The C. T. R. Wilson apparatus, improved by him since his first invention of it in 1899, enabled visual determination of the tracks produced by these ionizing charged particles. Principally because of the extensive use of this device, a description is made here with the diagram of the apparatus below.



C. T. R. Wilson's Cloud Chamber - from original.

When the valve B is opened the air beneath the glass plate under A rushes into the evacuated bulb C, and the plate drops onto the blocks D, increasing the volume of A.

The apparatus works on the principle that if a moisture-laden gas suddenly, adiabatically expands, condensation results. Wilson carefully controlled the ionization (without ions there is no condensation since they act on nuclei for the vapor particles) until alpha particles were shot into the chamber, these producing ionization and hence visible paths of condensation which were photographed. By means of this device, the radioactive disintegration series was studied and catalogued. These series offer proof as to the constitution of the elements by the formation of

new elements with new charge and mass upon the emission of electrons (Beta rays) or He nuclei (Alpha rays). Rutherford, too, commenced his investigations into the structure of the nucleus since this apparently was the seat of radioactivity. Probably, too, the most important immediate problem solved was by photographing the paths of the Alpha particles, wherein it was noticed that they had great penetration power, only occasionally producing a great deflection. This was explained on the basis that the very small volume of the nucleus repelled the positive alpha particle, since the concentrated nucleus is positive. This confirmed, to some extent, Rutherford's atomic theory, mentioned later.

<u>The Mass of the Electron Increases with Velocity</u>

Relativity was founded by Einstein in 1905 on the idea of the deviations in values involved when an observer describes a motion which is approaching the velocity of light. For small values, of course, the classical mechanics suffices. From this theory it was deduced that mass is a function of velocity[1]. Accordingly, the mass at any velocity is given by $m_v = m_o(1 - \frac{v}{c})^{2})^{-\frac{1}{2}}$ wherein m_v is any mass with motion, v, and m_o is mass at rest. Until the ratio v/c exceeds o.1 the relation is not appreciably increased. The "infinite limit" if the paradoxical expression might be used, is regarded as the velocity of light. Variations, in the case of the

1. Hudson's Electronics, p. 11, Wiley & Sons 1932.

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1. Hudson's Electronics, p. 11, Wiley & Sons 1932.

specific electronic charge, are presumably due to changes in m since e is regarded as constant. The mass, then, of Beta-particles of high velocity is subject to change.

The Proton - Positive Ray Analysis - Nuclear Disruption

Positive rays are given off by the anode of a vacuum tube opposite to the cathode rays. Goldstein, in 1886, discovered a similar ray, called canal rays, which leave a perforated cathode in opposite direction to the cathode and from their deflections in magnetic and electric field in the reverse order to the cathode rays, Goldstein, J. J. Thomson and others concluded they were positive electrical particles. Because they neutralize in the atom an equal number of electrons, it necessarily follows that their charge is equivalent to e. Their velocity and specific charge were obtained in the same manner as the electrons' and it was found they move more slowly, a few thousandths the velocity of light, while the ratio e/m was of the same order of magnitude as for electrolytic ions. Their mass, therefore, must be about the same as the mass of the atoms themselves. The phenomena of radioactivity verified the assumption that the constituents of atoms are protons and electrons.

The first critical experiment in the identification of the proton was performed by Geiger and Marsden in 1913 when they shot alpha particles from polonium into a sheet of gold foil and found that the bombardment caused an ejection of

positive particles of one-fourth the mass of an alpha particle. In 1914, Marsden detected scintillations on a fluorescent screen at a distance of 80 cm from some Hydrogen through which he was passing alpha particles. Since the range of these particles in H is only about 28 cm, the scintillations then were due to other particles produced by the alpha particles. A determination of specific charge resulted in their identification as H ions.[1]

Conclusive identification of the proton came in 1919 with Rutherford's bombardment of Nitrogen gas with alpha particles and ejecting from the nuclei of nitrogen the hydrogen nucleus. Subsequently, he disrupted the nuclei of twenty different elements and he found all have as a common nuclear constituent, the proton.[2]

Radii of the Electron and Proton

The radius of an electron can be computed if it is assumed it is spherical, a questionable assumption. An electron moving with velocity v and carrying charge e is associated in space[3] with electro-magnetic energy equal to $e^2v^2/3r$. Assuming, further, the concept of kinetic energy as due to the storage of electro-magnetic, by a substitution of proper units and equating

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1. Atomic Theory - Haas - p. 18; Constable Co., London.
2. Proceedings Royal Society, Vol. A 97, page 374.
3. Electronics - Hudson - p. 17; Wiley & Sons, 1932.

$v^2e^2/3r$ to $1/2\ mv^2$, the radius of electron has a value of 1.9×10^{-13} cm.[1] On this same basis, if the radius is inversely proportional to the mass, the proton has a radius 1/1850 that of the electron or about 10^{-16} cm.

Sketches of the Outstanding Atomic Theories

Lorentz' Theory, mentioned above, was followed by J. J. Thomson who, on the basis of his work with ray analysis and radioactivity, conceived the atom as consisting of a sphere of positive electricity in which the electrons were studded. Rutherford followed this theory by liking the atom to the solar system with electrons of size revolving about minute, heavy positive nuclei, the attractive pull being counterbalanced by centrifugal force of revolution. This had difficulties which were met by modifications of the theory by Dr. Niels Bohr, a Danish physicist, in 1913.

Mention must be made at this point of the Quantum theory of Planck, developed in 1901. In an effort to account for the radiant energy of a black body as it is distributed in different wave lengths, he assumed that the process of energy radiation takes place in small packets of varying size which he called quanta. The elementary quantum for any given wave length is equal to hv where v is the frequency and h is an absolute constant known as Planck's constant, of value 6.56×10^{-27} erg seconds (this value derived from his theory of thermal radiation).

1. Hudson's Electronic, Wiley's 1932, p. 17.

Rutherford's atomic model would disintegrate due to dissipation of energy. Bohr assumed an electron may revolve around the nucleus in different orbits with no radiation, since orbital velocities do not develop sufficient energy to radiate a succession of quanta. Radiation would take place with the jumping from one orbit or energy level to another. Spectral lines of various elements showed disagreement with this conception so that Sommerfeld enlarged the theory by assuming that the innermost orbit is always circular while all others are circular or elliptical.

Schrodinger followed Bohr in 1926 with the electron replaced by a small packet of high frequency electromagnetic waves in the ether. De Broglie succeeded him with the assumption that "the electron is neither a particle nor a wave but a combination of both, called a wavicle".[1] Ample evidence supports the corpuscular theory, and interference phenomena can be demonstrated by an electron stream producing waves that result in interference, evidence for the wave idea. Reconciliation of both conceptions is regarded as improbable, based on the Principle of Indeterminacy of Heisenberg in 1927.[2] The problem seems to be verging toward the region of metaphysics.

In any event, these atomic theories to date have contributed inestimably to the penetration of matter's constituents. The fruitfulness of these conceptions can never be questioned.

1. Hudson's Electronics, page 31.
2. Hudson's Electronics, page 31.

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III

THE NEUTRON

Speculation has been rife for the past two decades on the exact structure and nature of the atomic nucleus. Radioactivity, since its discovery in 1898 by the Curies, and Rontgen radiation characteristic of certain substances, discovered by Barkla in 1905, Marsden's discovery of H rays in 1914, Rutherford's first artificial disruption of an element with low atomic number in 1919, all afforded convincing proof of atoms being composed of protons and electrons. But radioactive radiation seems to prove that atomic nuclei are not built up directly of protons and electrons, but rather of aggregates of helium nuclei, alpha-particles, with a mass of four hydrogen atoms and a positive charge of two elementary quanta[1]. This proposition is supported by the fact that the most common atomic species have an atomic weight divisible by four. However, from the atomic weight 44 and upwards, the atomic weight is more than twice the atomic number, violating the form wherein if the atomic weight equals four n, the nuclear charge equals 2n, and instead, the atomic number becomes 2n' which increases until it equals 13, the thorium condition. It is hypothesized that the nuclei of these atoms also contain, besides alpha-particles of charge 2e, neutralized alpha-particles which contribute no charge but a mass of four units, and this hypothesis finds support in the

1. Haas' Atomic Theory, p. 124.

fact that in the radioactive disintegration series, a substance emitting alpha-rays is frequently followed by two beta-ray emissions, or a beta- by an alpha- and a beta-ray.

Still further investigations, since 1919, into the conditions of the atomic nucleus have brought forth amazing results. The main process employed consisted in a sort of regenerative system, wherein nuclear disintegration particles were used further to disrupt the nuclei of other atoms. And this in turn led directly to the discovery of the neutron.

In the Bakerian Lecture, delivered before the Royal Society of London in 1920, Lord Rutherford[1] reported on an investigation of the nuclear constitution of atoms. He attempted to disintegrate the light atoms of matter by collisions with swift alpha-particles, the helium nuclei, thinking by nature of the nuclear structure of the light atoms the nuclei might possibly penetrate one another's field or structure and probably not survive. He bombarded Nitrogen gas, among other substances, with alpha-particles from an active radium deposit, counted the scintillations on a zinc sulphide screen, and in a magnetic field noticed the deflections. The deflections were found to be less than those of the alpha-particles exciting them, evidence that the liberated particles are Hydrogen atoms of mass one (proven by comparison in tube of Carbon Dioxide and Hydrogen). The energy was believed to come from the fast alpha-particles

1. Proceedings of Royal Society, v. 97, p. 374.

of range 7cm in air which effected disintegration, or, possibly, from an attracted electron from an alpha-particle or a penetrating gamma ray, a product of the radioactivity of the radiation source. It is an unusual coincidence that Chadwick, in the Bakerian Lecture thirteen years later should be treating of practically the same experiment which presented to the world the neutron with many of its new properties.

It was J. S. Slater in England[1] who first made a detection of a small amount of gamma-radiation that was produced when the elements lead and tin were bombarded by alpha-particles emitted by radon. The German physicists, Bothe and Becker, as reported in Z. Physik., volume 66, page 289, 1930, verified this claim when they reported that some light elements when struck by the particles from Polonium emit radiations which appear to be of the penetrating gamma type. Less than a year later, Mme. Curie-Joliot found that bombarded Beryllium gave this marked effect[2] and that the radiation possessed a penetrating power distinctly greater than that of any gamma radiation yet found in the radioactive elements.

Because H. C. Webster's work[3] incorporated the main features of the above experiments plus additional improvements, his work will herein be briefly summarized.

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1. Philosophy Magazine, vol. 43, p. 904, 1921.

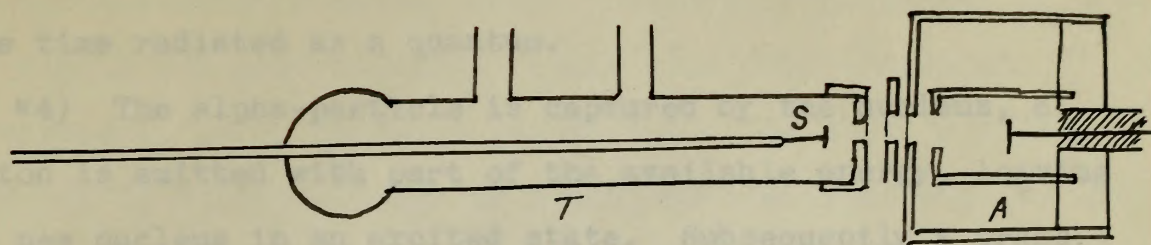
2. Comptes Rendus Académie Science, Paris, vol. 193, p. 1412, 1931.

3. Proceedings Royal Society, vol. A 136, p.428-453.

He observed the gamma-radiation (so-called) produced by the bombardment of the nucleus with alpha-particles for the elements Li, Be, B, F, Na, Mg, and Al (he obtained negative results with H, C, N, Ni, Cu, and Sn). Employing the Geiger-Muller tube counters (vide De Bruyne and Webster, Proc. Cambridge Phil. Society, vol. 27, p. 113, 1931 for diagram) because of its practicality and convenience, and a high pressure ionization chamber, as roughly shown on the following page, because of the small variation of the sensitivity of the apparatus with the quantum energy, he measured the absorption coefficients in lead and in some cases also in iron. Thereby, from the Klein-Nishina formula, the quantum energies of the radiations were deduced (after careful corrections due to the shortcomings of the apparatus). By comparison of the absorption coefficients in iron and lead, the Tarrant nuclear absorption coefficient was estimated. The quantum energies were found to range from about eight million electron-volts for boron to 0.5 million for sodium.

The ionization currents produced gave the absolute efficiencies of production of the various radiations which were found from 0.5 quanta per million alpha-particles for magnesium to about 30 quanta for beryllium. Webster attempted, further, to determine the processes responsible for these radiations and he concludes that the following four account for them in one way or another[1]:-

1. Proceedings Royal Society, vol. A 136, p. 445.



Chadwick, Constable & Pollards Ionization Chamber,- used by Chadwick[1].

S, polonium source on gold foil (serves to close tube, T); A, ionization chamber connected to positive pole of 1,000 volt battery, collecting electrode insulated by quartz and connected to grid of the first valve of the thyraton tubes in the amplifier.

"1) An inelastic collision takes place between the alpha-particle and the nucleus, without the capture of the alpha-particle. The energy lost by the alpha-particle is radiated as a quantum, as in the production of continuous X-radiation by electron impact.

"2) The same process occurs, save that the energy lost by the alpha-particle excites the nucleus, which later returns to its normal state, with emission of gamma-radiation.

"3) The alpha-particle is captured by the nucleus, a new normal nucleus being formed, and the surplus energy is at the

1. Proceedings Royal Society, vol. A 130, p. 463.

same time radiated as a quantum.

"4) The alpha-particle is captured by the nucleus, a proton is emitted with part of the available energy, leaving the new nucleus in an excited state. Subsequently a transition to the normal state takes place, with emission of a gamma-ray quantum." As later developments proved, Webster was correct in his assumption of capture and non-capture of the alpha-particle, although his quantum-hypothesis did not agree with experimental values of energy transferences."

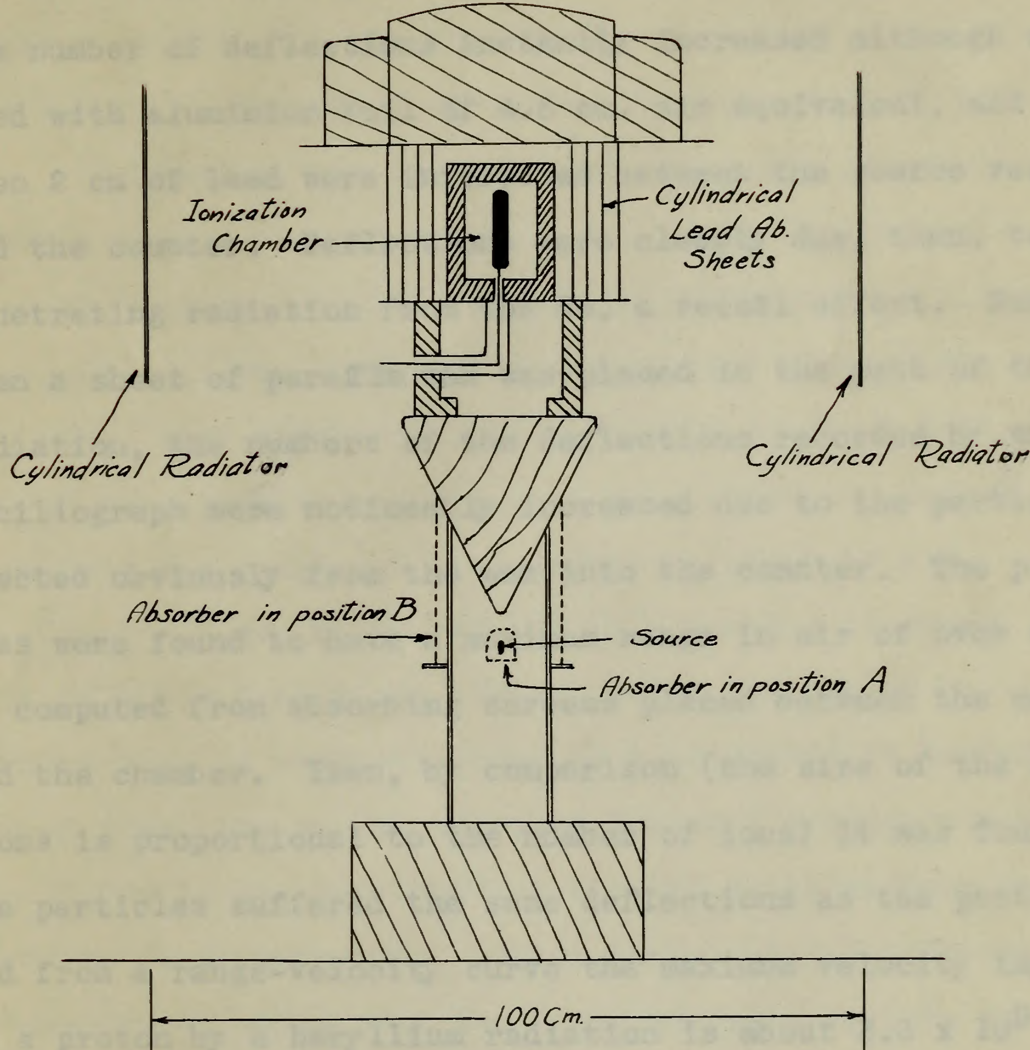
M. and Mme. (Curie) Joliot (as translated from Comptes Rendues Acad. Sci., Paris, vol. 194, p 273, 1932, by commentators), made the startling discovery that when these radiations from Be and B, first passed through a thin window into an ionization vessel containing air at room pressure, and were then passed through this window covered with paraffin wax, a hydrocarbon, the ionization in the latter case was greatly increased, sometimes doubled. Further, these radiations ejected protons of great velocity from the wax and the effect was ascribed to this by the Joliots. They thought energy was transmitted to the protons as energy is transferred in photoelectricity, and to the radiation gave high energy values, 50 x 10^6 electron volts, giving the protons ranges up to 26 cm, implying a velocity nearly the equal of light. However, these conclusions result in the violations of

the Klein-Nishina formula, which predicted a frequency of proton scattering many thousand times less than estimated. Furthermore, as J. Chadwick points out,[1] how does an alpha-particle of kinetic energy of 5,400,000 electron volts as the Beryllium nucleus produce a quantum of 50,000,000 electron volts? The greatest amount of energy available for radiation is the capture of the alpha-particle by the beryllium nucleus, atomic weight 9, and its incorporation into the nuclear structure to form Carbon, atomic weight 13, as expressed $Be^9 + \text{alpha} = C^{13} + \text{quantum}$. Since such is not the case, Chadwick made further investigations into the properties of the radiation excited in Be.[2] It was found that not only were particles ejected from the Be but also from H and all other light elements examined.

To describe briefly this experiment:- the properties were examined by means of the valve-counter used in the artificial disintegration by alpha-particles, consisting of a small ionization chamber connected to an amplifier and that in turn to an oscillograph. The apparatus is roughly diagrammed on the following page. Using old therapeutic radon tubes from the Kelley Hospital in Baltimore, Polonium was prepared and placed on a disc opposite a disc of Be in an evacuated chamber.

1. Proceedings Royal Society, Vol. A 136, p. 693.

2. Nature, Vol. 129, p. 312.



L.H. Gray's & G.P. Tarrant's High Pressure Ionization Chamber as used by Webster[1].

As demonstrated by Broxon[2], for the voltage employed in this experiment, the ionization produced is a reliable measure of the intensity of the radiation.

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1. Proceedings Royal Society, vol. A 130, p. 463.

2. Physical Review, vol. 37, p. 1320, 1931.

When this was placed before the ionization chamber, the number of deflections instantly increased although covered with aluminium foil of 4.5 cm. air equivalent, and even when 2 cm of lead were interposed between the source vessel and the counter. Deflections were clearly due, then, to a penetrating radiation from the Be, a recoil effect. Further, when a sheet of paraffin wax was placed in the path of the radiation, the numbers of the deflections recorded by the oscillograph were noticeably increased due to the particles ejected obviously from the wax into the counter. The particles were found to have a maximum range in air of over 40 cm as computed from absorbing screens placed between the wax and the chamber. Then, by comparison (the size of the deflections is proportional to the number of ions) it was found that the particles suffered the same deflections as the protons, and from a range-velocity curve the maximum velocity imparted to a proton by a beryllium radiation is about 3.3×10^9 cm/sec corresponding to an energy of about 5.7×10^6 electron-volts. Likewise, Be, B, Li, C, and N, as paracyanogen, were investigated. In every case, the deflections in the counter increased when shot with Be particles, although the range of the particles was only some mm. The deflections were of many sizes, however, and largely compared to that of a slow proton showing that the particles have great ionizing power and

probably are recoil atoms of the elements. Gases likewise produced similar effects wherein the radiation seems to impart energy to the atoms of matter through which it passes.

Based on the conservation of energy principle, Chadwick sensed discrepancies in the energy transference and primarily because of this formulated his neutron hypothesis. He argued:- if the energies of the ejected protons from the wax, etc., have energies up to 5,700,000 electron volts, then if the ejection results as a recoil from a quantum of radiation, the energy of the quantum hv given to mass m is $\frac{2}{2 \quad mc^2/hv} \cdot hv$, which results in a quantum of energy of about 55,000,000 electron volts. On an ionization basis, assuming that it requires about 35 electron-volts to form a pair of ions, the recoil atoms of N should produce not more than 13,000 pairs, but Chadwick counted pairs as many as from thirty to forty thousand. Other instances might be recorded, but experiment shows that too large energies must be assumed for the quanta striking the mass of the atoms. Not discarding the conservation of energy and momentum, Chadwick postulated that the quantum is not a radiation, but consists of particles of mass very nearly equal to that of the proton, thereby clearing the difficulties that arose with regard to their frequencies and to the energy transfer to different masses. He supposed it to consist of a proton and an electron in close combination, "a neutron", of no net charge, thereby ex-

plaining the great powers of penetration. In passing through matter the chargeless particle is permitted collision with the nuclei thereby giving rise to the recoil atoms mentioned above, which have all the velocities up to a maximum which is the same as the maximum velocity of the neutron. From this value, 3.3×10^9 cm per second, the maximum energy was calculated and found to agree with that found experimentally, based on the ionizing power as recorded in the counters. As an exception to this, however, it was noted that a few nitrogen recoil atoms ionized as high as 60,000 pairs. Dr. Feather, in his work[1] photographing the paths produced upon the collision of N nuclei with neutrons found cases wherein was represented nuclear disintegration (vide photographs p. 722, Proceedings Royal Society, vol. 136) without the capture of the neutron. Assuming that the disintegration followed the equation $N^{14} + n' = C^{12} + H^2 + n'$, there would be transferred sufficient energy to account for the production of the 60,000 pairs of ions. Of course, there are other possibilities, as the formation of the C^{13} isotope, or B^{10} and Helium, or the extreme Be^8 and Li^8, which will be omitted here. Chadwick compared the theoretical mathematical constants of the neutron with his experimental results in which he found the mass to be nearly the same as the proton. The energy he calculated from the expression $Be^9 + H^4 +$ kinetic energy of alpha $= C^{12} + n' +$ kinetic energy of $C^{12} +$ K E of n'.

1. Proceedings Royal Society vol. 136, p. 709.

Assuming the Be nucleus to consist of 2 alpha-particles and a neutron, then its mass cannot be greater than the sum of the particles' masses, since the binding energy corresponds to a defect of mass due to the packing effect.[1] Therefore, the above equation is $(8.00212 + n') + 4.00106 + \text{K E of alpha} > 12.003 + n' + \text{K E of } C^{12} + \text{K E of } n'$; or $\text{K E of } n' < \text{K E of alpha} - \text{K E of } C^{12}$. Determined from its ionizing power, the energy of the alpha-particle of Polonium is 5.25×10^6 electron volts, hence the energy of emission of the neutron cannot be greater than 8×10^6 electron volts. From this the neutron's velocity must equal 3.9×10^9 cm/second as compared to that velocity found experimentally, 3.3×10^9, quite in agreement.

Since some of the radiations from the Be fly backwards, Chadwick checked their properties on the bases of masses of about one and no charge and found the velocity computed agreed favorably with experimental results.

The most recent results from the Cavendish Laboratory[2] show the neutron to have the precise mass value of 1.0062, obtained from more careful experimenting. Substituting B for Be in the source vessel described, since the mass of the Be nucleus is unknown while from Aston's spectrographic measurements and from Jenkins & McKellar's optical methods[3] the mass

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1. Haas, Atomic Theory, p. 127.
2. Science News Letter, p. 44, Jan. 20, 1934.
3. Physical Review, Vol. 39, p. 549.

of the Boron nucleus is known, by this experiment the exact neutron mass can be calculated. Of course, the boron above disintegrates from B^{10} to B^{11} upon bombardment, as discovered by Chadwick in conjunction with Constable and Pollard[1] and this value can be substituted in the energy relation equation m of B^{11} + m of He^4 + KE of He^4 = m of N^{14} + m of n' + KE of N^{14} + KE of n', to result in the accurate value of 1.0062. Most recent "mass" development is of rather contradictory nature[2]. E. O. Lawrence allowed deutons to be bombarded with protons of energy of 3×10^6 volts. Showers of protons and neutrons were emitted, many with more energy than the impinging particles, protons. The only explanation is on a basis of reduced mass for the neutron of 1.0003,- further, too, does this upset the nuclear conceptions inasmuch as it implies the deuton and the proton are very unstable and causes question as to the real fundamental entities.

Viewing the neutron as a dipole or proton embedded in an electron, its radius would be about the order of 4×10^{-13} cm. Chadwick learned that the target areas for collision vary from about 3 to 6×10^{-13} cm for various substances. He also found that protons are more prone to collisions by neutrons than are electrons, despite their lesser radius. P. I. Dee[3] studied the interaction of neutrons with electrons

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1. Proceedings Royal Society, vol. 130, p. 464.

2. Science News Letter, Feb. 3, 1934.

3. Proceedings Royal Society, vol. 136, p. 727.

by means of the Wilson cloud track chamber and concluded that in comparison with the N nuclei it is extremely small, less than 1%! Nuttall and Williams accorded a smaller range to recoil electrons than was actually computed, working from the given ionizing power. Dee asserts, however, that the existence of neutrons would stand on the observance of a range from a recoil of less than 3.4 mm of air, since the quantum hypothesis would demand the range of the recoil electron in the order of meters of air. As far as can be determined, this difficult experiment has not been verified to date.

Harkins, Gans and Newson[1] disintegrated light atomic nuclei, Ne, N, etc.,- they discovered an important item wherein in disintegration by capture of a neutron the Kinetic Energy decreases, sometimes is conserved, but never increases.

Crane, Lauritsen, and Soltan[2] bombarded Be with deutons of 900,000 e v and produced a yield of neutrons hundreds of times greater than with He nuclei.

Neutron of Mass 2

Evidences of a neutron of mass 2 have been reported by Walke of Exeter, England,[3] wherein by studying the photographs of the particles made at Chicago by Professor Harkins[4]

1. Nature, p. 358, Sept. 2, 1933.
2. Physical Review, Oct. 15, 1933, p. 692.
3. Science News Letter, Aug. 26, 1933, p. 131.
4. Physical Review, vol. 46, p. 584, 1933.

he found energy values to 17,000,000 electron volts or twice the normal energies of the neutron of mass 1. Rutherford[1] further postulates neutrons of mass 2 might be secondary units in nuclei structure. Indeed, fundamentally, Heisenberg has hypothesized the probability of atomic nucleus as composed of neutrons and protons only, and Professor Allen, FRS,[2] has drawn up a table of such atomic structure.

The Deuton - H^2

Because of recent experiments involving the isotopes and the new particles, it would be well here to speak of the isotopes of H, called deuterium with the nucleus called the deuton, or, as Rutherford insists, diplogen. Urey, Brickwidde and Murphy[3] showed by optical methods the existence of an isotope of H of mass 2 which could be concentrated chemically by distillation. This conformed with Berge and Menzel's prophecy when[4] they pointed out that upon the discovery of two isotopes of oxygen to bring the results of the mass spectrograph into accord with the chemists, hydrogen must have two isotopes. Sir J. J. Thomson discovered that gas rich in H^3 by bombarding certain substances, such as solid KOH, with cathode rays.

1. Proceedings Royal Society, vol. A 136, p. 737.
2. Nature, p. 322, Aug. 26, 1933.
3. Physical Review 40, p. 1, 1932; 39 p. 164, 1932.
4. Physical Review 37, p. 1669, 1931.

It is assumed the neutral H^2 nucleus is composed of 2+ and 1- or 1+ and 1 neutron by computing the mass which was found[1] to be 2.01351

According to Sexl of Vienna[2] the magnetic momentum of the proton is greater than it should be if it were an elementary particle, from Stern's experiments. Therefore, the proton consists of a neutron and positron (discussion of this follows). This theory, however, is far from universally accepted, but is a development of Dirac's work with the "anti-electron".

In an attempt to dissociate the H^2 nucleus by bombardment with alpha-particles Rutherford[3] found that the number of neutrons, if any, was certainly less than 1 in 10^7 of the number of bombarding alpha-particles. From scattering effects of the particles by deutons he concluded that the field of force surrounding the diplon is sensibly the same as that of the proton.

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1. Bainbridge, Physical Review, p. 42, Oct. 1, 1932.
2. Nature, p. 174, July 29, 1933.
3. Proceedings Royal Society, vol. A 143, p. 724, Feb. 1, 1934.

IV

THE POSITRON

Cosmic Rays

By demonstrating with a specially designed electroscope, C. T. R. Wilson has shown that the charge on the leaves will dissipate themselves slowly through dry air which is ordinarily considered almost a perfect insulator. As early as 1903 Rutherford found that ions can always be detected in the air, which he attributed to a very penetrating type of radiation[1], which is much less absorbed by radiation, and harder than X or gamma rays. Hess and Kohlhorster in 1912-1914 made the first serious study by observing their nature at various altitudes with different screening devices employed. Gockel, a Swedish physicist, noted the intensity of these rays still prevalent at a height of 4500 meters in an equipped balloon. Millikan, in 1925,[2] determined their wave lengths, (they are not homogeneous), by finding their absorption coefficient below the surface of snow-fed lakes, at great altitudes (believed to be of a secondary variety in accord with the Compton effect) and in air (primary rays), and found these to be as small as $\frac{1}{2}$X-unit (1/1000 of Angstrom unit). He employed the equation $I = I_0 e^{-d\mu}$ wherein d is the thickness of the absorbing media, μ the

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1. J. A. Crowther, "Ions, Electrons & Ionizing Radiation," 4th, Longmans, Green Co.

2. Nature, Vol. 116, p. 823, 1925.

absorption coefficient, and I_0 and I are the initial and final intensities.

In passing, as to the origin of cosmic rays, they were so named because their cause was attributed to the formation of nuclei of atoms in the outer regions of the universe with consequent energy loss, due to mass defects in radiation, or as Nernst described it, "the birth of matter". These, however, are only speculations. Kohlhorster plotted a graph of intensity curves from observations made in mountain glaciers and at altitudes from balloons, and found the intensity greatest when the stars that form the milky way were highest in the sky, and least twelve hours later. He concluded the milky way with its numerous young stars and nebulae to be the source of the radiation, calculating the union of H nuclei and electrons to form helium nuclei or the plunge of an electron into the nucleus of an atom to be the energy sources of these penetrating rays. However, more recently, Millikan and Anderson photographed the paths of the particles by these ionizing "rays" in a Wilson cloud chamber under the influence of a magnetic field and found them to have a curvature, in the case of the electrons ejected, as some were, of energy as high as 20×10^6 e.v, and in the case of the ejected protons as high as 50×10^6. Obviously, then, the results indicate the nuclei of the atoms in the chamber have been disrupted by impact with

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either high energy neutrons or ultra-gamma rays. Millikan strongly tended toward the photon theory.

A different view is offered by Dr. T. H. Johnson[1] who made 10,000 observations of these rays in various sections of the continent and concluded that cosmic rays are the positively charged nuclei of matter, charged by the action of starlight on interstellar gas, and accelerated in some cosmic or terrestial electric field. The nature of the charges are determined by the bending of paths in a magnetic field. Johnston used the Geiger-Mueller counting devices wherein, as mentioned before, electrical impulses are set up by the entering rays and recorded photographically to show that, for some unknown reason, more are found in the western than in the eastern sky. This idea is somewhat verified as a result of observations made during a balloon ascension ten miles into the stratosphere in the Fall of 1933 by Settle and Fordney. Drs. Arthur Compton and J. J. Stephenson of the University of Chicago[2] announced to the American Physical Society, February 24, 1934, that these rays consist conclusively of positively charged particles responsive to terrestial polar influences, upsetting Dr. Millikan's photon theory. The flight revealed the presence of still another type of ray above the atmosphere. Further flights, especially in the Polar regions, will undoubtedly

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1. Science News Letter, p. 356, Dec. 2, 1933.

2. New York Times, Feb. 25, 1934.

do much to substantiate or expand the conclusions. Exact data is not yet available. (Incidentally, these conclusions of high energy bearing charged particles support the LeMaitre-Vallarta theory of the development of the cosmos from a single radioactive star.)

The Positron

It was in the investigation of these cosmic rays that Carl Anderson in 1931, at the California Institute of Technology discovered the positron. Previously, in 1931, P. A. M. Dirac of Cambridge University had, through brilliant mathematical formulations, prophesied the existence of a positively-charged particle of the mass and dimensions of the negative electron, an electron bearing negative energy. The Joliots, in the Spring of 1932, had produced them artificially, unknowingly, attributing the results to electrons travelling back to the source of emanation.

An Outline of Anderson's Work[1]

Following the work of others, including Shobelzyn, Occhialini, et al., Anderson was investigating the absorption and ionizing powers of the cosmic rays in a Wilson cloud chamber apparatus.[2] He varied the conventional procedure by arranging his apparatus with the breadth of the ionizing

1. Scientific Monthly, p. 5, January, 1934.

2. Science, Vol. 76, p. 238, 1932.

chamber in a vertical plane, contrary to practice, by fitting into it a lead plate several mm thick, and by endowing it with a very strong magnetic field. By careful analysis of a photographed track made by an ionizing "ray", Anderson found its curvature indicated its positive charge, the length of the line its great velocity, ~~while~~ he observed its thinness eliminated possibility of its identity as a swift proton or alpha particle of high energy. Thibaud, by the deflection method of measuring charge-to-mass ratio found that it is almost certainly between one-half and twice that of the negative electron.[1] Dirac, Chadwick, Blackett and Occhialini were first to manufacture the positive electron.

Blackett and Occhialini at the Cavendish Laboratory (diagram, p.42) had set up two Geiger-Muller counters, one on each side of the expansion chamber, so controlled that when they simultaneously recorded reactions from the passage of an ionizing particle, the chamber expanded. Their photographs revealed tracks in opposite directions of curvature originating from a single point and indicating electrons of opposite signs.[2] Going further, with Chadwick, they bombarded Be with alpha-particles from Po to produce neutrons and high v photons, as described, which impinged on the lead in the chamber and produced similar tracks from the artificially created "showers". Meitner and Phillip in Dahlern[3]

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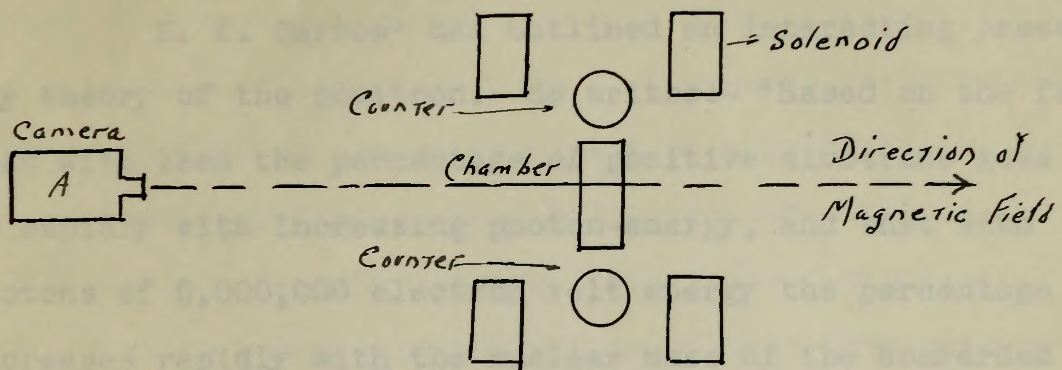
1. Nature, Vol. 131, p. 473, 1933.
2. Proceedings Royal Society, Vol. A 142, p. 24.
3. Naturwiss, vol. 21, p. 283, 1933.



Chadwick's Apparatus with Counters[1]

Rays must pass through both the counters and chamber.

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verified this experiment with duplication of results. The Joliots' experiment was similar and they later rechecked using Al and lead and found in the latter case the results were much more numerous.

In an effort to determine whether the photons or neutrons ejected the positrons from the lead, M. & Mme. (Curie) Joliot found that, by screening the neutrons emitted from the Be nucleus by the Po radiation, the reduction of positron emission was not in proportion to the fall, hence establishing the photons as the cause. This presents the fact that high frequency gamma rays with energies of 5,000,000 to 1,000,000 e.v. can produce positive electrons without the presence of neutrons. This filtration is discussed in Comptes Rendus, 196 p. 1105, 1933.

1. Proceedings Royal Society, p. 717, vol. A 139.

K. K. Darrow[1] has outlined an interesting present day theory of the positron. He writes:- "Based on the facts that with lead the percentage of positive electrons goes up rapidly with increasing photon-energy, and that with photons of 5,000,000 electron volt energy the percentage increases rapidly with the nuclear mass of the bombarded atoms, it is supposed that a photon transmits itself into a pair of electrons, one of each sign." This leaves us to account for the distribution of the excess energy of the 5×10^6 electron volt photons. Einstein's mass energy relation, $E = mc^2$, gives the two electrons at rest mass translated into energy of over 1,000,000 electron volts. The residual energy from the high-speed photons might go into the Kinetic Energy of the electrons, or into a new photon, or divide itself between these forms. The theory demands paired electron, positive and negative, production. Such has not always been the case, however, but discrepancies have been explained as being due to several things, e.g., absorption of the electron by metals in the case of the isolated positron, or excess of negative electrons as due to ordinary photon-atomic collisions. It further follows that positrons should only be produced by gamma-rays of high energy and such has been borne out by the negative results obtained from Polonium gamma-radiation.

The theory postulates the conservation of momentum

1. Scientific Monthly pp. 12-13, January, 1934.

as well as energy, but to maintain this an atom must be present at the paired production. Otherwise, as Darrow points out, if a photon produced two electrons with no atom present to balance, the momentum concerned would produce in one electron velocity greater than that of light.

With respect to absorption of high frequency photons by heavy elements, it has been discovered that with very heavy elements and very high frequency gamma-rays, the total absorption is greater than can be ascribed to absorption from simple deflection, from the photo-electric effect, and from a Compton collision with an electron. This extra absorption is now ascribed to the photons which convert themselves into electron pairs, agreeing with the facts that the extra absorption increases rapidly with frequency of gamma-rays and atomic weight of metal. Further, since the paired electrons at rest have energy of over 10^6 electron-volts, their production under this value is as yet unobserved as is this additional absorption with gamma-rays of less than this energy value. Gentner in Paris substantiated this conception to some degree when he plotted an experimental curve of extra absorption against frequency, extrapolated it, and found the extrapolated curve comes down to zero at just about the frequency where the photon has sufficient energy, theoretically, to create an electron pair, 10^6 electron volts. Oppenheimer and Plesset have confirmed this process of light into

electrons mathematically in the light of the quantum-mechanical theory.

W. Furry, N.R.F.,[1] mathematically developed Dirac's theory of the electron and concluded that for electrons of high energy the production of + and − electron pairs is important and theoretically probable.

Anderson theorizes[2] that positrons must be secondary particles ejected from the atomic nucleus. He further imagines the proton to be expanded to the electron's size upon impinging with the incoming primary ray, thereby releasing a billion electron-volt energy as a secondary photon. Alternately, he offered the idea of a neutron's disintegration without the issuance of a photon, but demanding <u>the existence of an unknown negative proton</u>.

Before concluding, a description of the latest results in producing positrons will show the progress being achieved. Anderson's method of artificial production[3] was as follows: He passed gamma-rays from Th C" through lead on to an Al plate, and by noting the decrease of energy after passage through Al, he photographically discovered positrons among the electrons ejected from the lead. With Neddermeyer, he concludes[4] that the incident energy of the

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1. Physical Review, p. 238, Aug. 1, 1933.
2. Physical Review, v. 43, March 15, 1933.
3. Science, Vol. 77, p. 432.
4. Physical Review, p. 1034, June 15, 1933.

radiation supplies the energy for the liberation of the + and - electron.

Anderson arrived at a questionable conclusion in his study with cosmic rays (in light of recent discovery), assuming with Millikan that the rays[1] consist of photons in great part, when he found that equal numbers of + and - electrons were released, unlike the results of gamma-radiation. He concludes this is "in accord with the assumption that the nuclear effects involved give rise to positives and negatives in pairs (several at times as observed in showers) and that this type of absorption represents nearly the whole absorption for rays in the energy range of hundreds of million volts". However, Cassen of California Institute of Technology[2] objects to this conclusion as incompatible with high primary energies and claims this (i.e., the formation of very high energy positive nuclei from a penetrating primary) could only be due either to ejection of heavy nuclear parts by high gamma-radiation or by neutrons to be found in primary radiation.

The Joliots recently produced 30,000 positrons a second from a leaf of Al foil exposed to the bombardment of alpha-particles from a very strong Polonium source. Thibaud, too, has produced streams of positrons from capsules of radioactive salts enclosed in silver or lead, strong enough

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1. Physical Review, p. 406, vol. 44, Sept. 1, 1933.

2. Physical Review, p. 513, vol. 44.

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1. Physical Review, p. 406, vol. 44, Sept. 1, 1933.
2. Physical Review, p. 518, vol. 44.

to cause a fluorescent screen to emit light enough to be photographed.

As reported very recently[1] Joliot and Thibaud announced to the French Acadamy of Science that the positron is short-lived and produces instantly two gamma-rays or photons travelling in opposite directions of a total energy of 1,000,000 e.v., when it unites with a free e, but if e is bound ina nucleus only the positron would be destroyed and one photon emitted. This was mathematically foretold by Dirac. The life of the positron is calculated to be 1/100,000 second.

1. Science News Letter, p. 109, Feb. 17, 1934.

V

CONCLUSIONS

Since the passing of the so-called Newtonian physics with the advent of the study of the particular nature of electricity and light, electronic physics has been progressing at almost a frenzied pace. With amazing rapidity there have developed the various atomic theories based on the discoveries of Hertzian waves and Roentgen rays, cathode rays, conduction in gases, and the famous Michelson-Morley experiment. Most accurate measurements of the elementary electrical charge and of the elementary energy quantum have been computed in the last four decades.

And progress toward the ultimate structure of matter is yet moving with sure swiftness to possible completion. From Prout's first hypothesis, the nature of matter is being more and more laid bare to the prying methods of mathematics and experiment. With the spectrograph, ionization, absorption, to present pictures of the unseeable; from abstract energy values to measure concrete mass and linear dimensions; by chemical means and electrical devices to learn properties of the seemingly intangible; all these the modern physicist is employing with increasing dexterity and ingenuity.

Witness the parade of atomic entities brought to

light,- the electron and proton, the alpha-particle, the neutron, the positron with their complex combinations in the elements and their isotopes. Professor Ladenburg of Princeton asks, "just what is the ultimate nature of mass?". Is it a combination of electron and proton, is the neutron a fundamental particle, or the deuton, or the positron, or is the proton, as is probable, really complex, consisting of a neutron and a positron?[1] Already the debate, fostering further tireless investigation, has commenced. For example, according to Sexl of Vienna[2], the magnetic momentum of the proton is greater than it should be if it were an elementary particle. Therefore, he argues, the proton consists of a neutron and a positron. This theory, however, is far from being universally accepted but is one development of Dirac's work with the "anti-electron". And thus does speculation, motivating theory formulation and verifying experiment, instantly spring up as to the place in the physical world of these electronic strangers.

Perhaps the near future will disclose many startling facts. Fundamental concepts seem to be tottering, the conservation of energy and momentum, considered basic, are now being seriously questioned as applicable to nuclear physics. Matter may be definitely reduced

1. Scientific Monthly, Vol. 36, p. 467.

2. Nature, p. 174, July 29, 1933.

to the general category of wave phenomena and yet answer the question as to how wave energy can concentrate itself into a quantum packet. The entire scheme seems to be most intricate in light of recent discovery and theory,- yet to quote Dr. Landenburg, "the only difficulties in nature are found in the artificial processes, man-designed, to unravel nature's secrets".

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* Direct reference.

** Read for some references and indirect scientific background.